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MULTIPATH MEASUREMENTS

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An outline of the final report to be issued during August 1974 is provided. Major topics to be covered are Multipath Theory, Experimental Measurements, Computer Simulation and Proposed Plans and Schedule for Phases II and III. Included also is material presented at a recent Design Review which describes technical progress to date.

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for

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MULTIPATH MEASUREMENTS

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ABSTRACT

An outline of the final report to be issued during August 1974 is provided. Major topics to be covered are Multipath Theory, Experimental Measurements, Computer Simulation and Proposed Plans and Schedule for Phases II and III. Included also is material presented at a recent Design Review which describes technical progress to date.

Section 1. INTRODUCTION

This is the Midterm Technical Report (CDRL Item A002) on Contract No DAAH01-74-C-0704.

At a meeting held on 28 May 1974, Raytheon was directed by Mr. Sam Uptain, USAMC, and Major John Meinhardt, ARPA, to keep this report to minimum size because of the short program schedule. Specifically, the report is required to contain primarily an outline of the final report (due mid August 1974).

The required outline is provided in Section 2. In addition, to indicate technical accomplishments to date, copies of VuGraphs discussed at the recent Design Review meeting (18 June 1974) are presented in Section 3. The program is currently up to date according to the Project Schedule on the third VuGraph (Figure 3).

Section 2. FINAL REPORT OUTLINE

A preliminary outline for the final report is provided in Table 1. A short description follows for each of the major headings. Currently available details are referred to as they appear on the VuGraphs of Section 3 (Figures 1-34).

2.1 Introduction

Included will be statements of program objectives (Figures 1, 2), and summaries of the experimental concept chosen (Figures 4, 5) and the methods to be used in collecting and analyzing data. Options of varying degrees of sophistication may exist; these will be briefly described.

2.2 Multipath Theory

The advanced multipath theory implemented by the computer simulation will be described briefly utilizing basic material from references 1 and 2. Additional features resulting from the current effort will be carefully discussed (Figures 14-19).

2.3 Experimental Measurement

Trade-off studies of geometry, power levels and hardware options, (Figures 6-12, 32, 34) will be presented and the selected configuration (Figures 28-31, 33) described in some detail. Included will be rationale related to selection of measurement sites and support (balloon, helicopter) for the beacon transmitter (Figures 25-27).

The measurement approach discussion will define types of data to be taken and the progression of recommended sites representing a progression from simple to sophisticated terrain (or water).

The data analysis discussion will be based on the concepts portrayed in Figure 24.

Ref. 1. The Scattering of Electromagnetic Waves from Rough Surfaces by Beckmann and Spizzichino, Pergamon Press, 1963.

Ref. 2. Low Angle Radar Tracking by David K. Barton, IEEE Proceedings, June 1974.

Table 1.

Final Report Outline

Abstract

Section

1. Introduction

   Total Program Objective
   Phase I Objectives
   Brief Description of Experimental Concept
   Summary of Data Collection and Analysis Plans including Options

2. Multipath Theory

   Classical Theory
   Modifications Recently Developed

3. Experimental Measurements

   Trade-off Studies
   Selected Configuration
   Measurement Approach
   Data Analysis

4. Computer Simulation

   Program Inputs and Outputs
   Computational Capabilities
   Typical Results
   Desirable Future Options

5. Proposed Plans and Schedules for Phases II and III

Appendices

   A. Summary Flow Chart and Listing of Computer Simulation Program
   B. Equipment Specification
   C. Equipment Implementation Plan
   D. Measurement Plan
   E. Data Analysis Plan

2.4 Computer Simulation

The capabilities of the computer simulation will be described (Figure 13) in some detail and all input and output parameters defined (Figures 18, 20). Typical results applicable to both experimental situations and some tracking conditions will be provided. Some preliminary examples are shown in Figures 21-23. Additional options not currently included, but which would enhance the validity of the simulation, will be recommended for incorporation at a later date.

2.5 Proposed Plans and Schedules

Recommended plans and schedules for gathering and analyzing definitive data (Phases II and III) will be provided. These will include recommendations for electronic and support equipment, such as:

1. receiving antenna, pedestal, receiver, and computational facilities aboard a van or trailer,
2. beacon transmitter, balloon, and tethering equipment.

Also, specific sites will be proposed for measurements. Reasonable schedules for equipment acquisition and assembly and for taking and reducing data will be given.

The specifications and plans in Appendices B-E will provide detailed backup for this section.

2.6 Appendices

Contained herein will be a listing and flow chart to supplement the computer simulation (Section 2.4) as well as the specifications and planning documents developed as part of the Phase I effort.

Section 3. DESIGN REVIEW MATERIAL

At a design review meeting, the material in Figures 1-34 was presented. These figures represent technical progress to date. The figures are organized as follows:

1. Program Objectives and Schedule
   Figures 1 to 3
2. Experimental Concept
   Figures 4 to 12
3. Multipath Computer Simulation, Theory and Data Analysis
   Figures 13 to 24
4. Experimental Configuration including site selection, electronic hardware and support equipment.

Figure 1.

MULTIPATH MEASUREMENTS PROGRAM

TECHNICAL OBJECTIVES

- REFINE CLASSICAL MULTIPATH THEORY
- MEASURE TERRAIN AND SEA REFLECTION PHENOMENA
- QUANTIFY EXISTING THEORY
- ACCURATELY PREDICT RADAR TRACKING AT SHALLOW GRAZING ANGLES
- DEVISE TECHNIQUES FOR IMPROVING TRACKING ACCURACY

TOTAL PROGRAM PHASES

I MEASUREMENTS PROGRAM DESIGN

II MEASUREMENTS PROGRAM

III DATA REDUCTION INCLUDING MULTIPATH HANDBOOK

Figure 2.

PHASE I

April 30 - Aug. 15, 1974

DEVELOP MULTIPATH COMPUTER MODEL

- o SIMULATE MEASUREMENT EXPERIMENT
- o SIMULATE TRACKING RADAR

DEFINE MEASUREMENT CONCEPT

- o HARDWARE FOR MEASURING REFLECTION COEFFICIENT
- o SELECT SUITABLE MEASUREMENT SITES

GENERATE SPECIFICATIONS AND PLANS

- o EQUIPMENT
- o MEASUREMENTS
- o DATA ANALYSIS

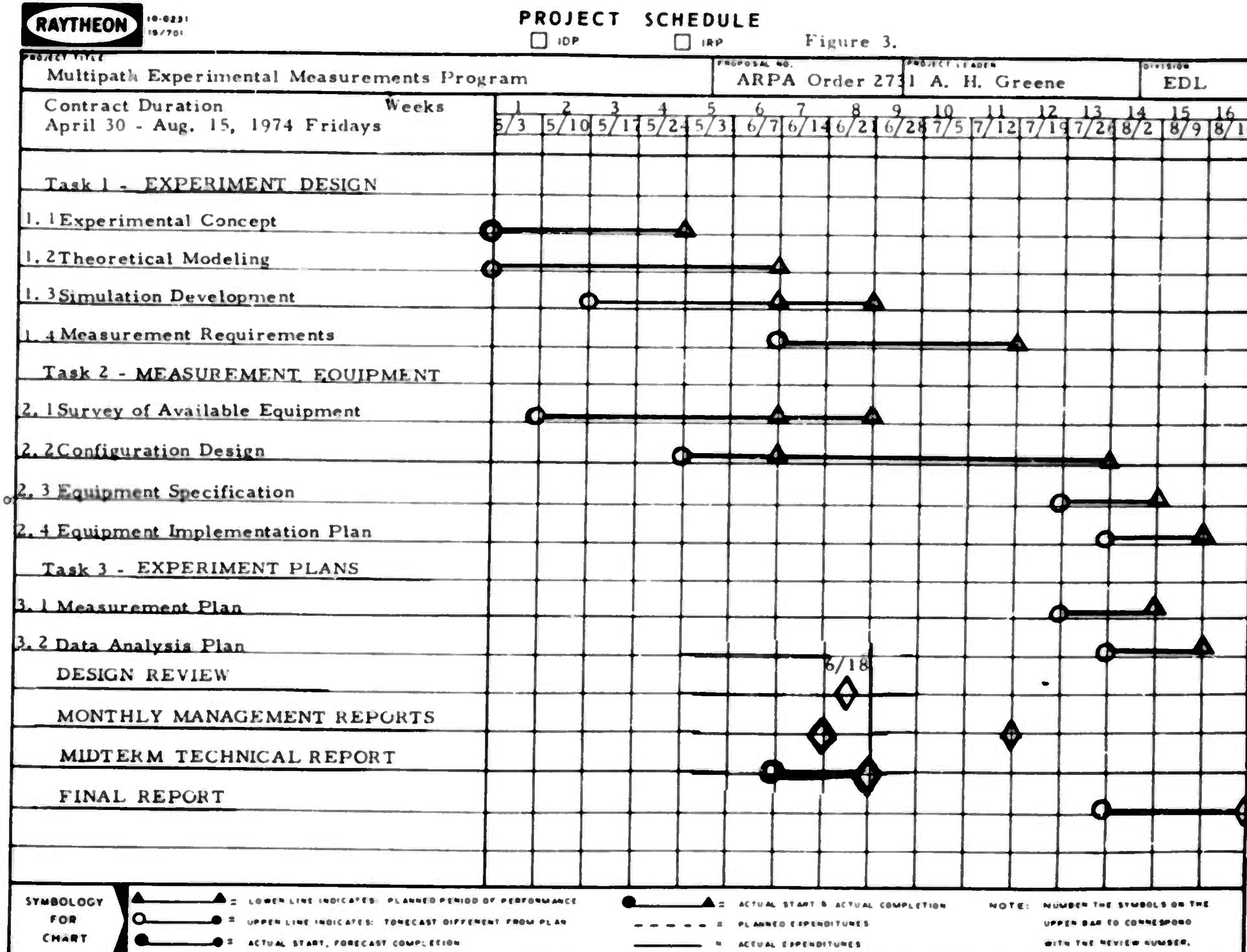
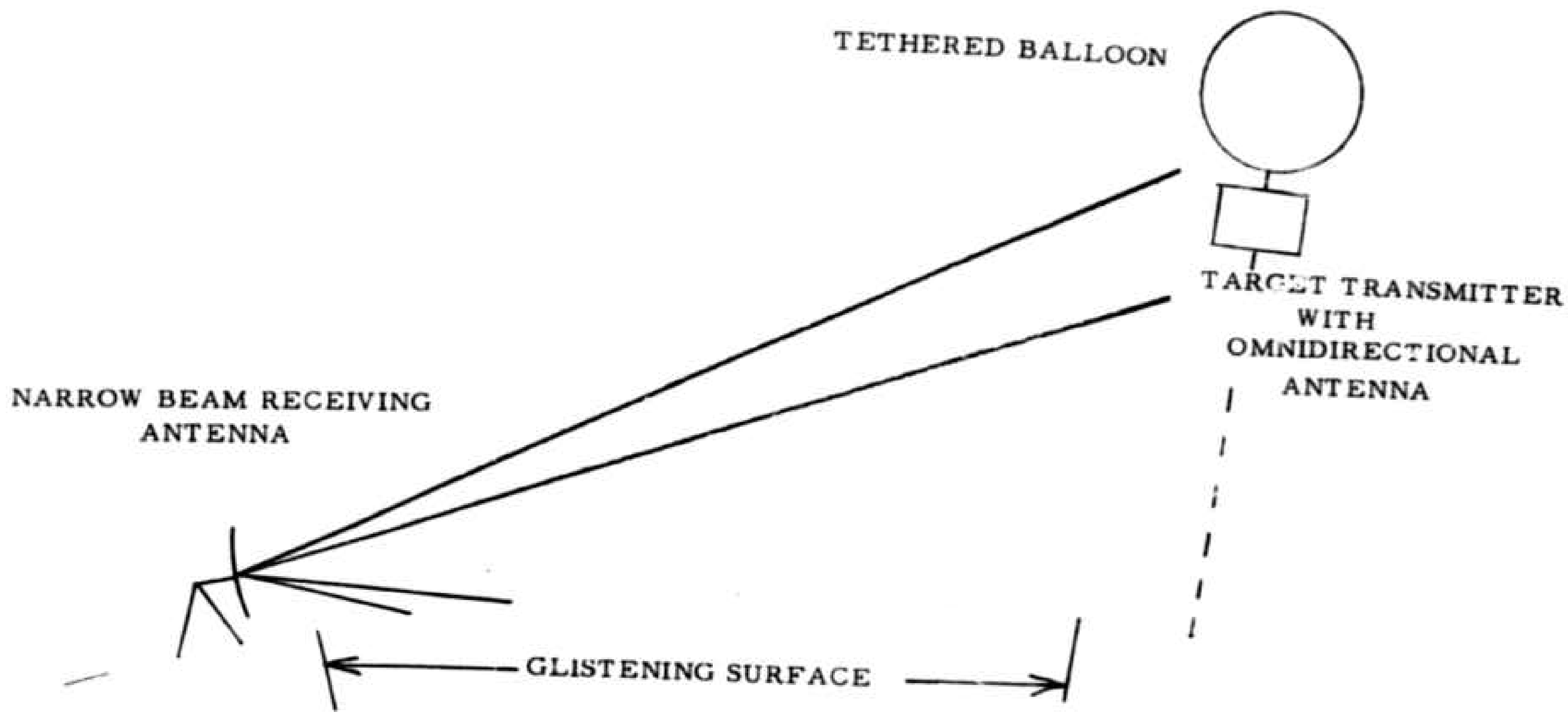

RAYTHEON
10-0231
18/70
PROJECT SCHEDULE
IDP
IRP
Figure 3.
PROJECT TITLE
Multipath Experimental Measurements Program
PROPOSAL NO.
ARPA Order 2731
PROJECT LEADER
A. H. Greene
DIVISION
EDL
Contract Duration
April 30 - Aug. 15, 1974 Fridays
Weeks
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
5/3 5/10 5/17 5/24 5/31 6/7 6/14 6/21 6/28 7/5 7/12 7/19 7/26 8/2 8/9 8/16
Task 1 - EXPERIMENT DESIGN
1.1 Experimental Concept
1.2 Theoretical Modeling
1.3 Simulation Development
1.4 Measurement Requirements
Task 2 - MEASUREMENT EQUIPMENT
2.1 Survey of Available Equipment
2.2 Configuration Design
2.3 Equipment Specification
2.4 Equipment Implementation Plan
Task 3 - EXPERIMENT PLANS
3.1 Measurement Plan
3.2 Data Analysis Plan
DESIGN REVIEW
6/18
MONTHLY MANAGEMENT REPORTS
MIDTERM TECHNICAL REPORT
FINAL REPORT
SYMBOLOGY FOR CHART
= LOWER LINE INDICATES: PLANNED PERIOD OF PERFORMANCE
= UPPER LINE INDICATES: FORECAST DIFFERENT FROM PLAN
= ACTUAL START, FORECAST COMPLETION
= ACTUAL START & ACTUAL COMPLETION
= PLANNED EXPENDITURES
= ACTUAL EXPENDITURES
NOTE: NUMBER THE SYMBOLS ON THE UPPER BAR TO CORRESPOND WITH THE REVIEW NUMBER.

Figure 4.

EXPERIMENTAL CONCEPT

- o RELIABLE AND REPRODUCIBLE DATA NEEDED
  - MINIMIZE EQUIPMENT COMPLEXITY
  - SELECT UNIFORM TERRAIN

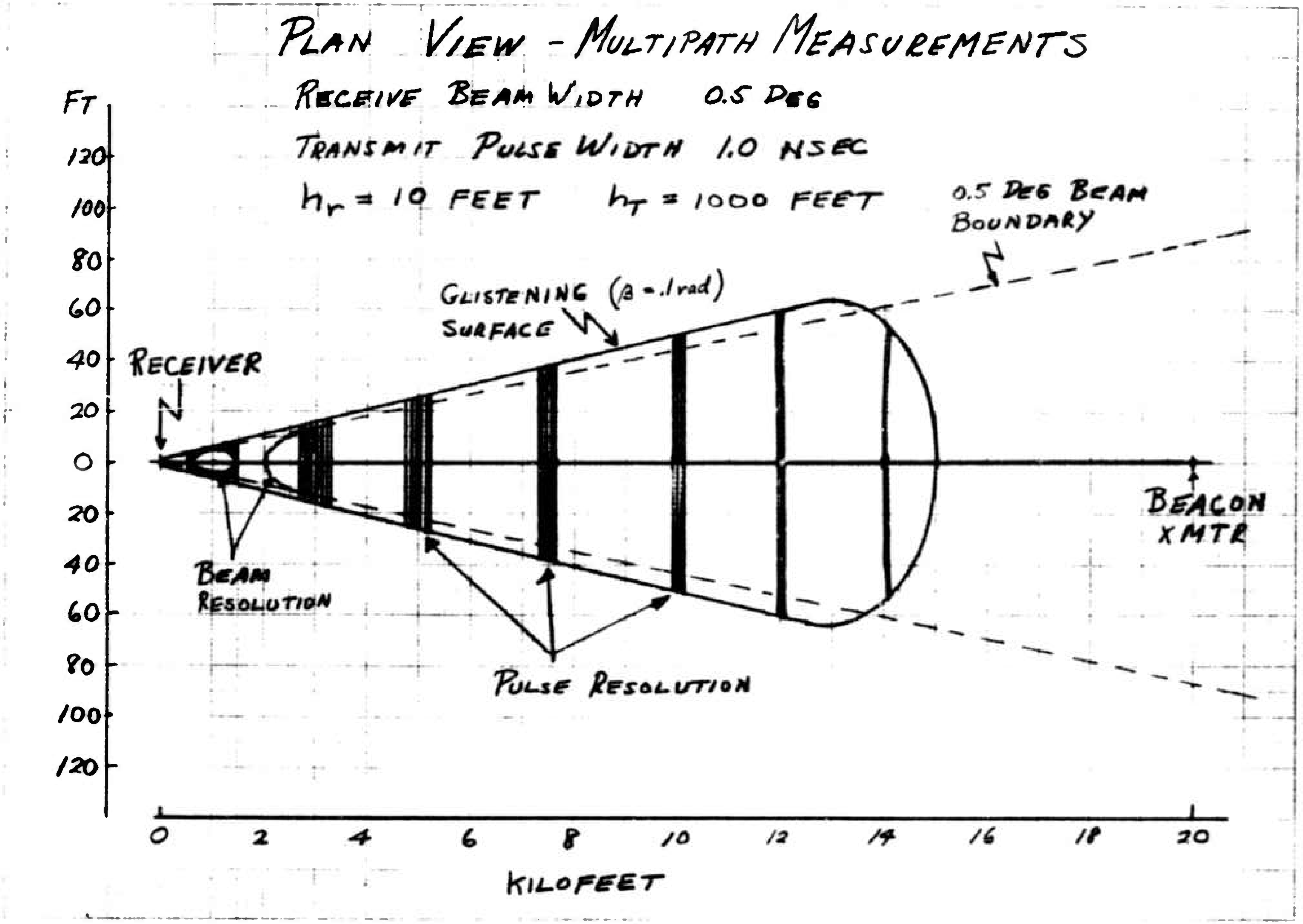
- o CANDIDATE MEASUREMENT CONCEPT
  - TETHERED BALLOON - PULSED BEACON
  - WIDE BAND GROUND RECEIVER
  - K_u BAND ($\approx$ 16 GHz) AND X OR C BAND
  - SINGLE NARROW RECEIVE BEAM
  - HOMOGENEOUS TERRAIN - GRASS, DESERT



PICTORIAL OF THE PLANNED EXPERIMENT

Figure 5.

Figure 6.



PLAN VIEW - MULTIPATH MEASUREMENTS
RECEIVE BEAM WIDTH 0.5 DEG
TRANSMIT PULSE WIDTH 1.0 NSEC
h_r = 10 FEET h_T = 1000 FEET
0.5 DEG BEAM BOUNDARY
GLISTENING SURFACE (β = .1 rad)
RECEIVER
BEAM RESOLUTION
PULSE RESOLUTION
BEACON XMTR
FT
120
100
80
60
40
20
0
20
40
60
80
100
120
0
2
4
6
8
10
12
14
16
18
20
KILOFEET

HEWLETT PACKARD

Figure 7.

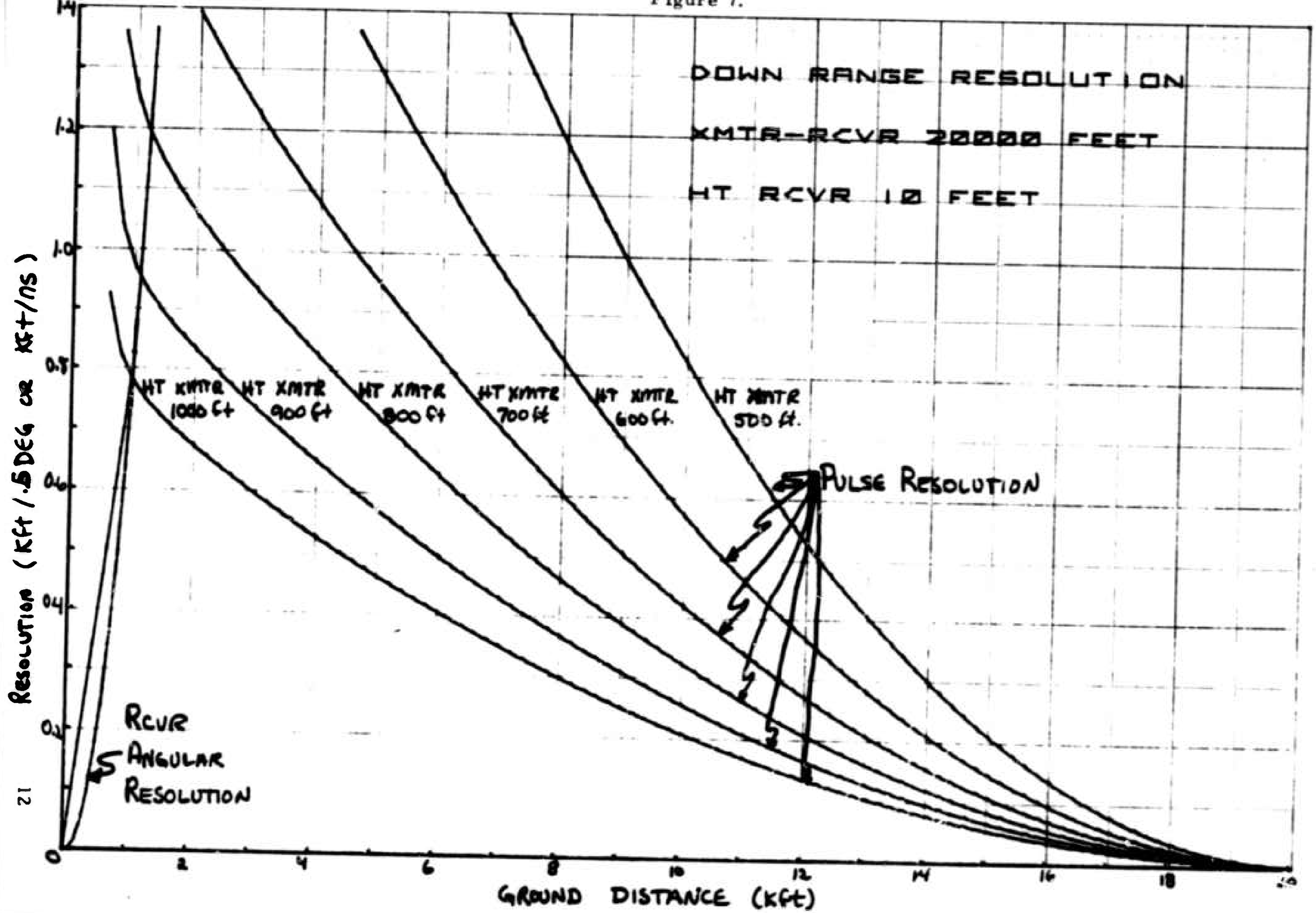
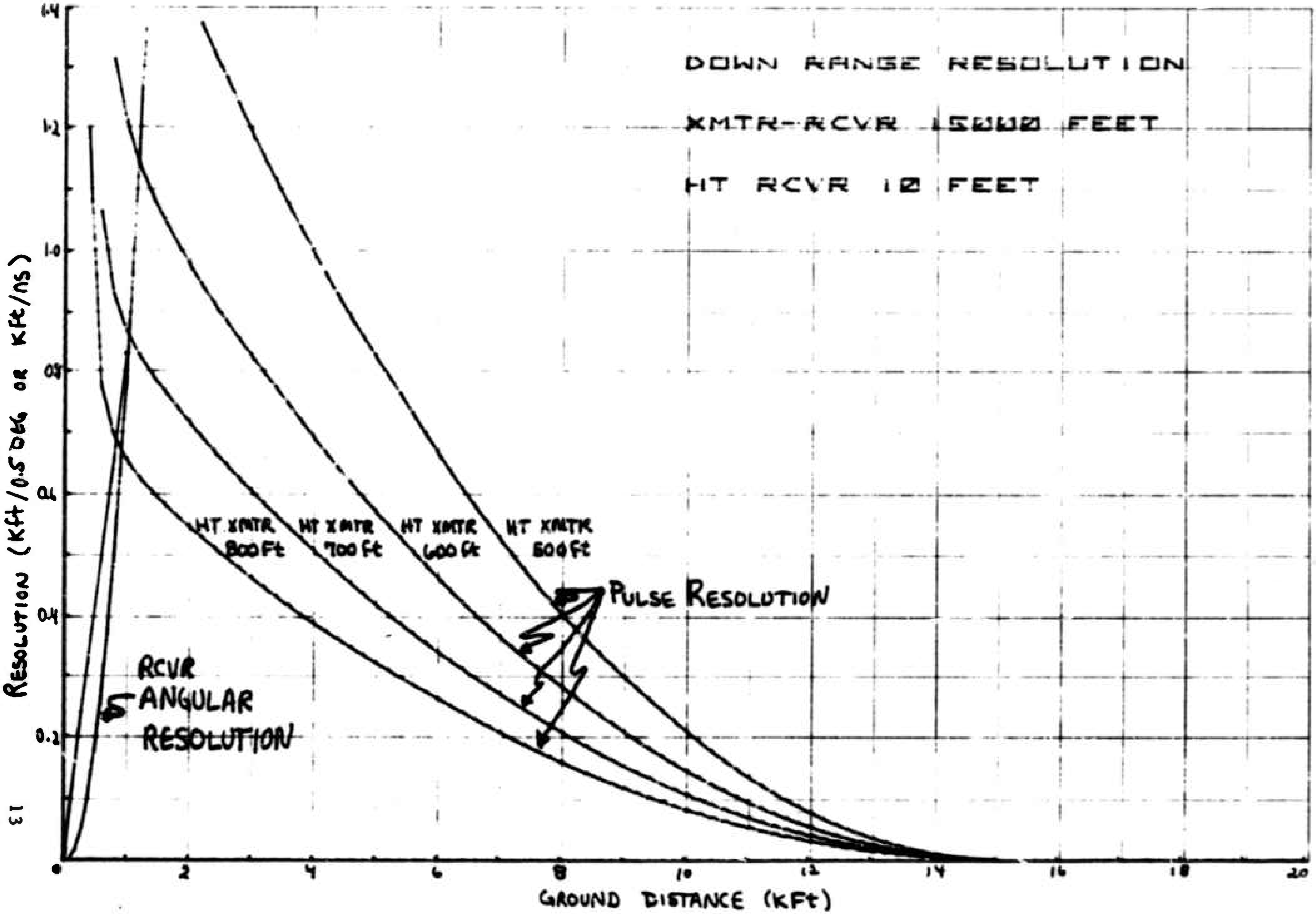


Figure 8.



DOWN RANGE RESOLUTION
XMTR-RCVR 15000 FEET
HT RCVR 10 FEET
HT XMTR 800 Ft
HT XMTR 700 Ft
HT XMTR 600 Ft
HT XMTR 500 Ft
PULSE RESOLUTION
RCVR ANGULAR RESOLUTION
RESOLUTION (KFt/0.5 DEG OR KFt/ns)
GROUND DISTANCE (KFt)
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
2
4
6
8
10
12
14
16
18
20

Figure 9.

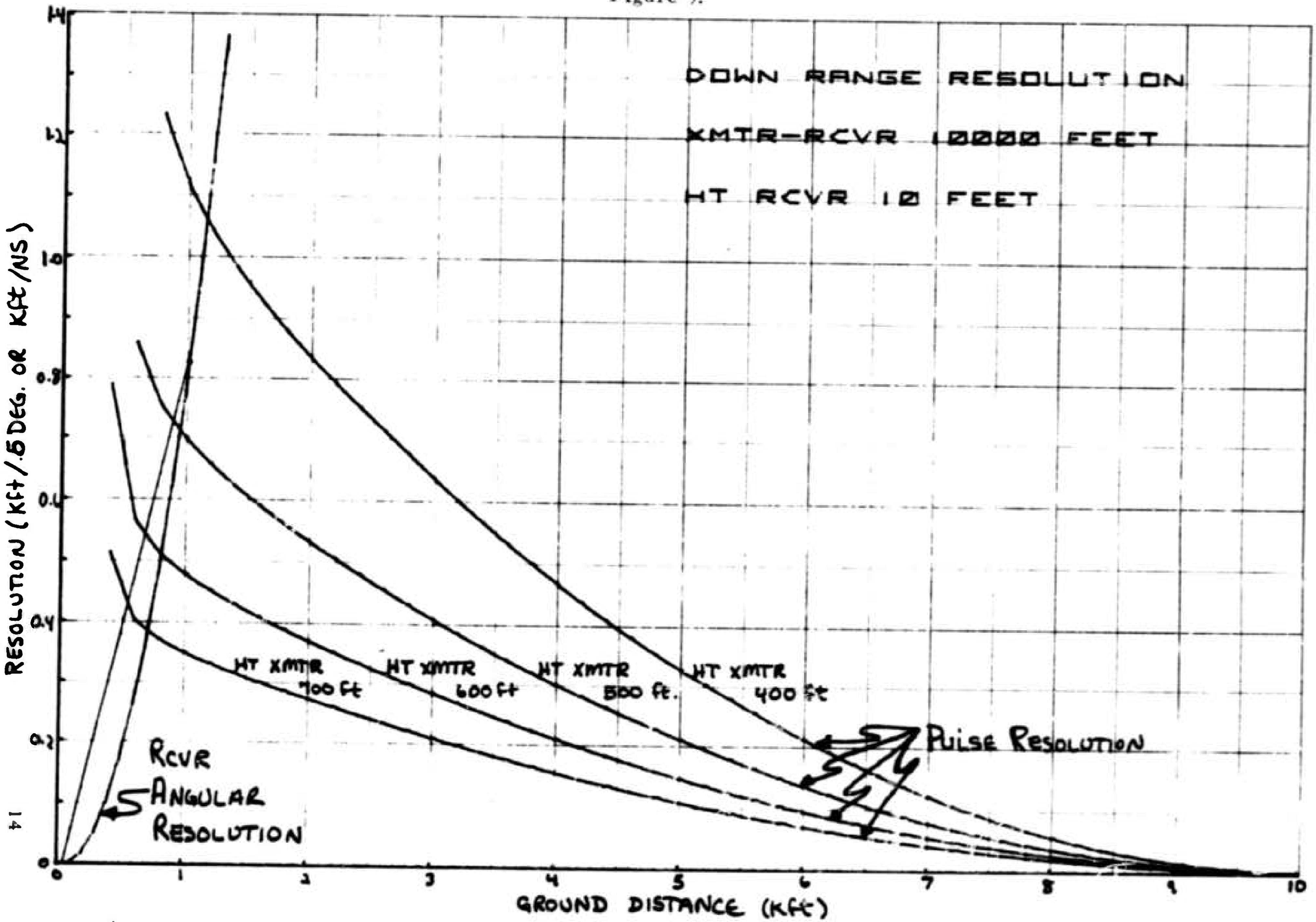
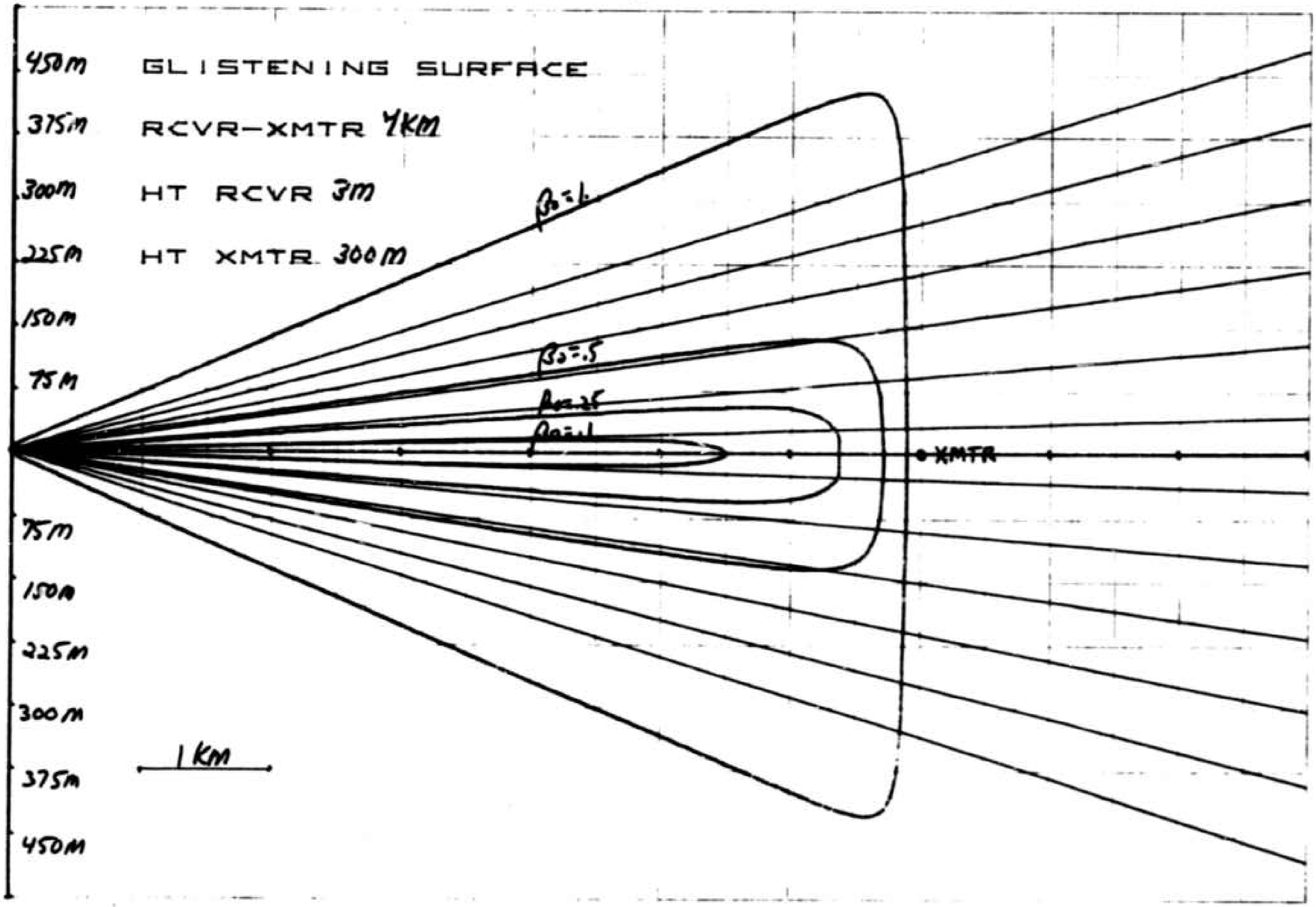
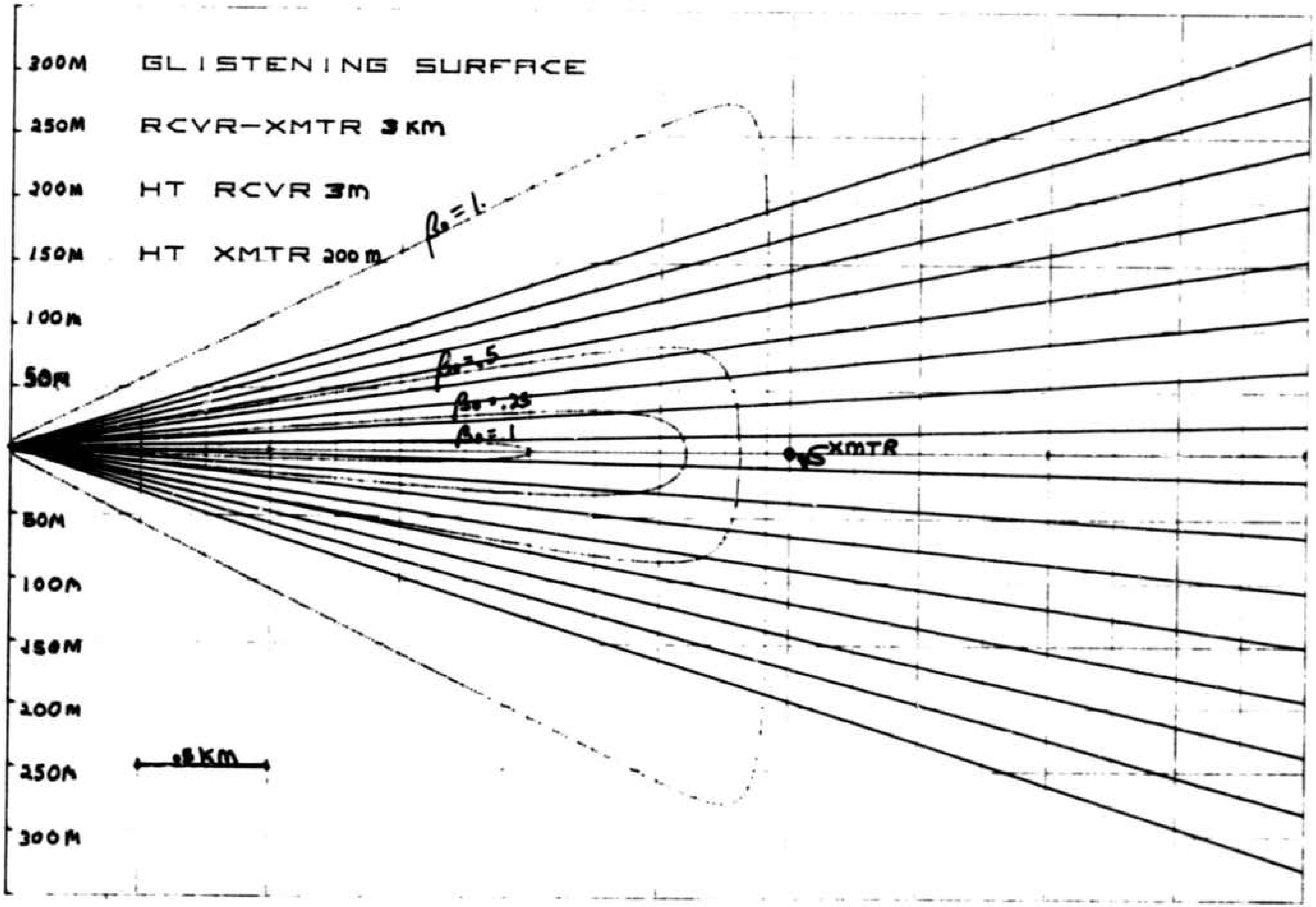

DOWN RANGE RESOLUTION
XMTR-RCVR 10000 FEET
HT RCVR 10 FEET
HT XMTR 700 ft
HT XMTR 600 ft
HT XMTR 500 ft.
HT XMTR 400 ft
PULSE RESOLUTION
RCVR ANGULAR RESOLUTION
RESOLUTION (Kft/.5 DEG. OR Kft/NS)
GROUND DISTANCE (Kft)
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1
2
3
4
5
6
7
8
9
10

Figure 10.



450m
375m
300m
225m
150m
75m
75m
150m
225m
300m
375m
450m
GLISTENING SURFACE
RCVR–XMTR 4KM
HT RCVR 3m
HT XMTR 300m
β0=1
β0=.5
β0=.25
β0=.1
XMTR
1 KM

Figure 11.



300M
250M
200M
150M
100M
50M
50M
100M
150M
200M
250M
300M
GLISTENING SURFACE
RCVR-XMTR 3 KM
HT RCVR 3m
HT XMTR 200 m
$\beta_0 = 1.$
$\beta_0 = .5$
$\beta_0 = .25$
$\beta_0 = .1$
XMTR
.5KM

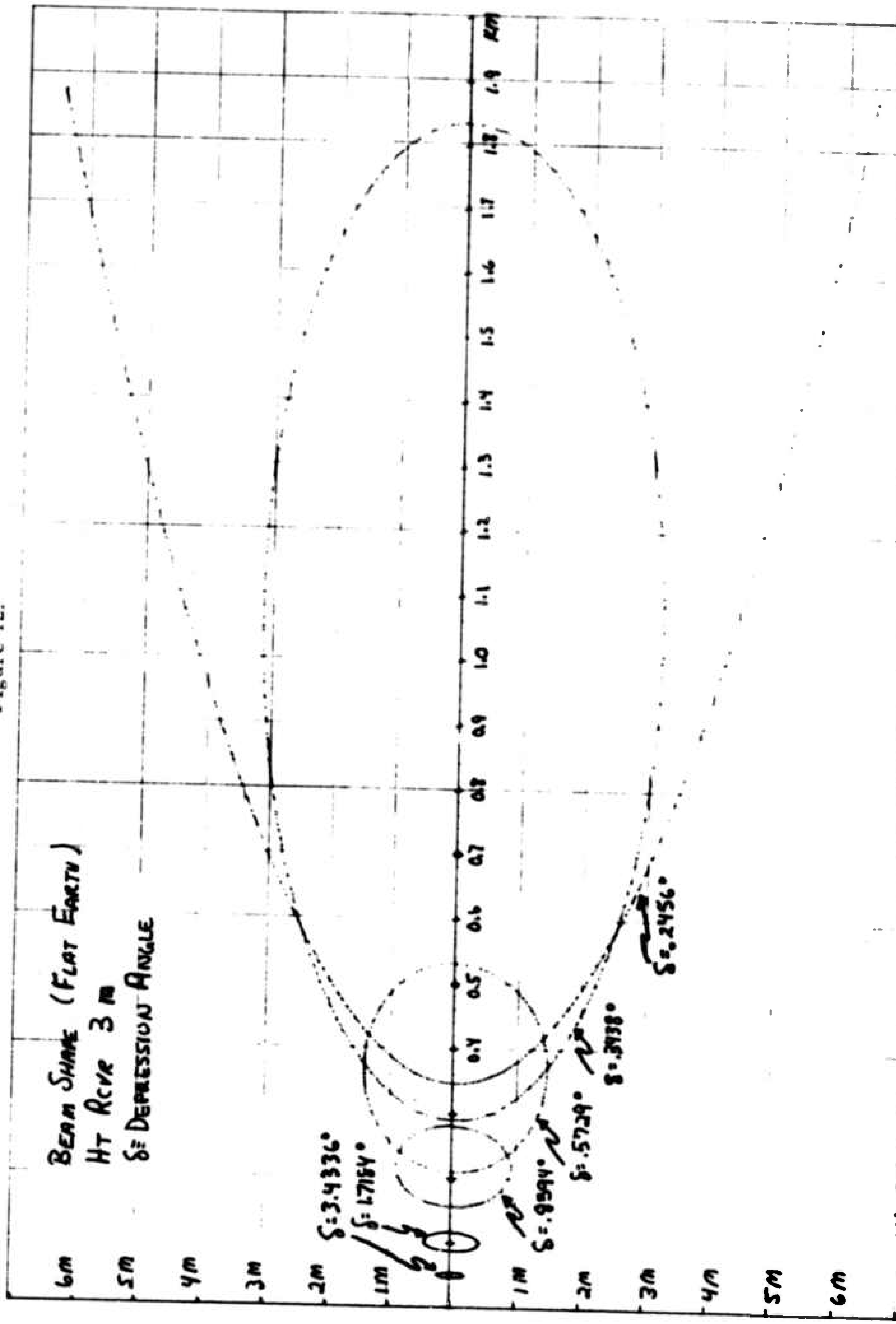

Beam Shape (Flat Earth)
Ht Rcvr 3 m
δ= Depression Angle
δ=3.4336°
δ=1.7184°
δ=.9594°
δ=.5729°
δ=.3938°
δ=.2456°
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
1.2
1.3
1.4
1.5
1.6
1.7
1.8
1.9
Km
6m
5m
4m
3m
2m
1m
1m
2m
3m
4m
5m
6m

Figure 12.

Figure 13.

MULTIPATH COMPUTER SIMULATION

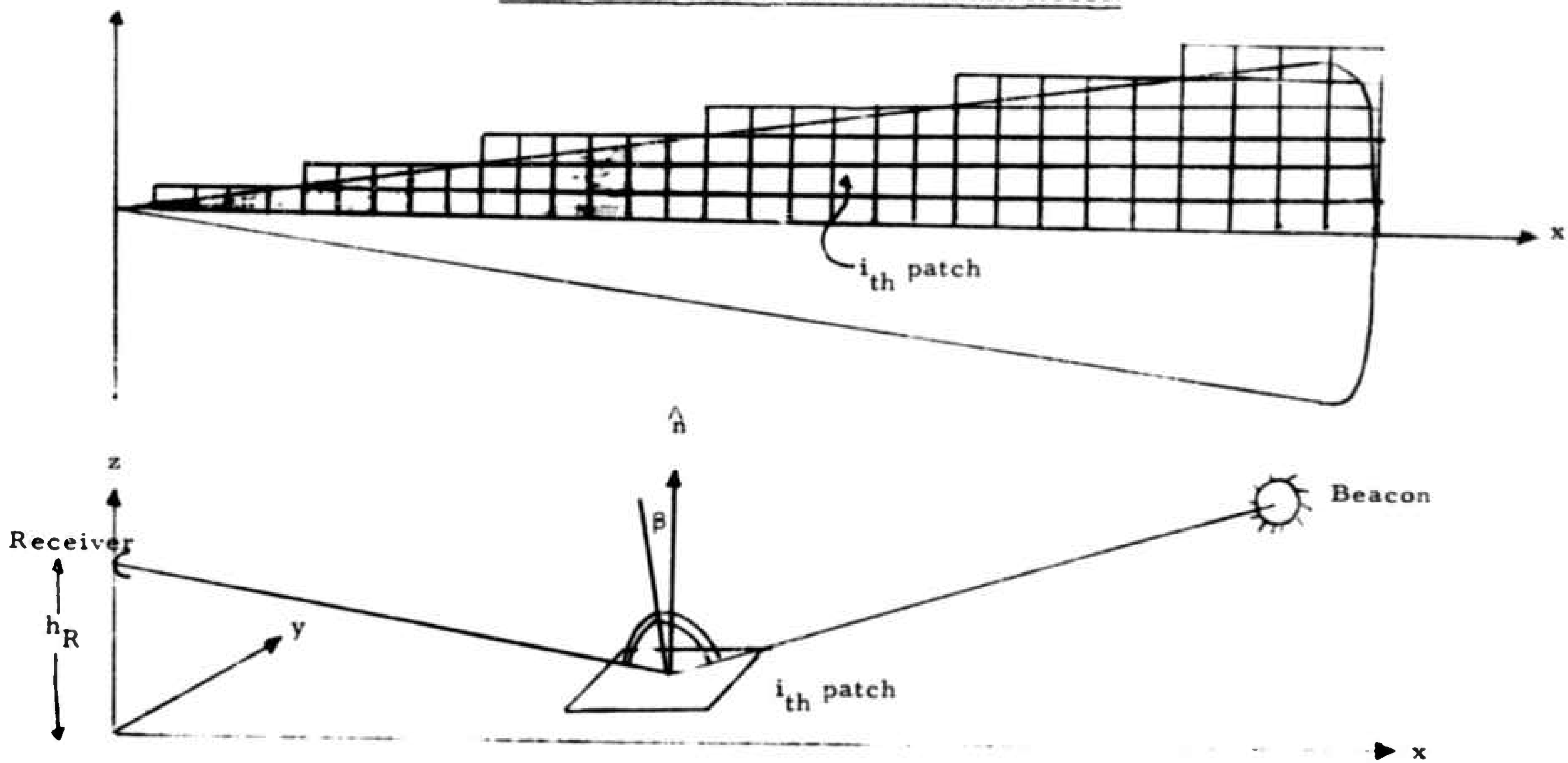
OBJECTIVE: MEASURE MULTIPATH RETURNS AND TRACKING ERRORS

PROGRAM INCLUSIONS

- MEASUREMENT AND TRACKING MODES
- EQUIPMENT CONFIGURATIONS
  - PASSIVE RECEIVER - PULSE BEACON
  - PASSIVE RECEIVER - CW BEACON
  - PULSE RADAR - PASSIVE TARGET
  - CW RADAR - PASSIVE TARGET
- CURVED EARTH GEOMETRY
- GROSS TERRAIN FEATURES
- VEGETATION FACTOR
- SMALL SCALE SURFACE ROUGHNESS MODIFICATION

Figure 14.

GLISTENING SURFACE DETERMINATION



- Uniform surface slope distribution: $\beta \leq \beta_0$
- Gaussian surface slope distribution: $\beta \leq 3\beta_0$, $\sigma = \beta_0$

  ($\beta_0 \equiv$ max. absolute slope of surface irregularities)

Figure 15.

PATCH POWER DETERMINATION

o Specular Patch Power

$$\Delta P_s = \frac{(\lambda \rho_v R_o D \rho_s)^2 P_T g_T g_R}{(4\pi)^3 (R_1 + R_2)^2} \delta s$$

$$\rho_s = \rho_o(\psi_1, \psi_2, \psi_3) e^{-g/2}$$

$$\rho_o \approx \begin{cases} 0 & \text{outside 1st few fresnel zones} \\ 1 & \text{as } \psi_1 \rightarrow \psi_2 \text{ and } \psi_3 \rightarrow 0 \end{cases}$$

$$g = \frac{4\pi \sigma_h}{\lambda} (\sin \psi_1 + \sin \psi_2)^2$$

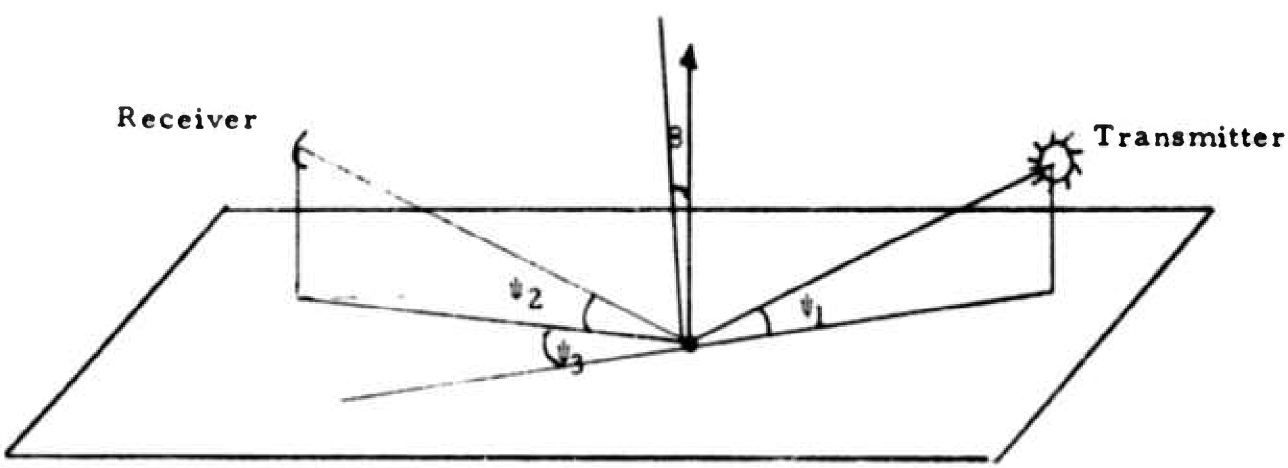


Figure 16.

PATCH POWER DETERMINATION

- Diffuse Patch Power

$$\Delta P_d = \frac{(\lambda \rho_v R_o)^2 P_T g_T g_R}{(4\pi)^3 R_1^2 R_2^2} F_d^2(\psi_1, \psi_2) G(\beta, \beta_o)\delta s$$

$$F_d^2(\psi_1, \psi_2) = \sqrt{(1 - \rho_{s1}^2)(1 - \rho_{s2}^2)}$$

$$\rho_{si}^2 = \mathrm{Exp}\left[-\left(\frac{4\pi\sigma_h \sin\psi_i}{\lambda}\right)^2\right] \quad i = 1, 2$$

$$G(\beta, \beta_o) = \begin{cases} \cot^2(\beta_o) & \text{for } \beta \le \beta_o \\ 0 & \text{for } \beta > \beta_o \end{cases} \qquad \text{(Uniform)}$$

$$G(\beta, \beta_o) = \begin{cases} \cot^2(\beta_o)\,\mathrm{Exp}\left(-\dfrac{\tan^2\beta}{\tan^2\beta_o}\right) & \text{for } \beta \le 3\beta_o \\ 0 & \text{for } \beta > 3\beta_o \end{cases} \qquad \text{(Gaussian)}$$

- Total Patch Power

$$\Delta P = \Delta\rho_s + \Delta\rho_d$$

Figure 17.

TOTAL POWER

Option 1:

$$\text{power} = \sum_{\text{all patches}} \Delta P$$

Option 2:

$$\text{voltage} = \sum_{\text{all patches}} (\pm) \sqrt{\Delta P}\; e^{j\,\Delta\alpha}$$

$$\Delta\alpha = \frac{2\pi\Delta R}{\lambda} + \phi$$

ϕ = phase of fresnel reflection coefficient

$$\Delta R = \Delta R_{max}\,\mathrm{Ran}(0,1) + \Delta R_{min}(1 - \mathrm{Ran}(0,1))$$

$$\Delta R_{max} = \Delta R_o + \left|(\sin\psi_1 - \sin\psi_2\cos\psi_3)\frac{\Delta x}{2}\right| + \left|\sin\psi_2\sin\psi_3\frac{\Delta y}{2}\right| + \left|\cos\psi_1 + \cos\psi_2\right|\sigma_h$$

$$\Delta R_{min} = \mathrm{Max}(0,\ \Delta R_o - \Delta R_{max})$$

$\Delta R_o \equiv$ Path difference at center of patch

$$\text{Power} = |\text{VOLTAGE}|^2$$

Figure 18.

PROGRAM INPUTS

o PEAK POWER AND ANTENNA GAIN OF TRANSMITTER

o RECEIVING ANTENNA PATTERN AND GAIN

*o Δx, Δy

o RECEIVER/TRANSMITTER HEIGHTS

o RECEIVER/TRANSMITTER GROUND RANGE

o PULSE SHAPE

o FREQUENCY

o NOISE FIGURE

o BEAMWIDTH/POINTING DIRECTIONS

*o SURFACE STATISTICS

Figure 19.

SURFACE STATISTICS

- SMALL SCALE ROUGHNESS
  - SURFACE DISTRIBUTION
    - MEAN SURFACE HEIGHT = 0
    - SURFACE HEIGHT VARIANCE (σ_h^2)
    - CORRELATION DISTANCE (T)
    - MAX ABSOLUTE SLOPE OF SURFACE IRREGULARITIES

      ($\theta_o = \tan^{-1}\left(\frac{2\sigma_h}{T}\right)$)
  - ELECTRICAL PROPERTIES OF TERRAIN
    - DIALECTRIC CONSTANT
    - CONDUCTIVITY
  - GROSS TERRAIN FEATURES
    - LOCATION wrt RECEIVER
    - MEAN HEIGHT PER PATCH
    - MEAN x & y SLOPES PER PATCH

Figure 20.

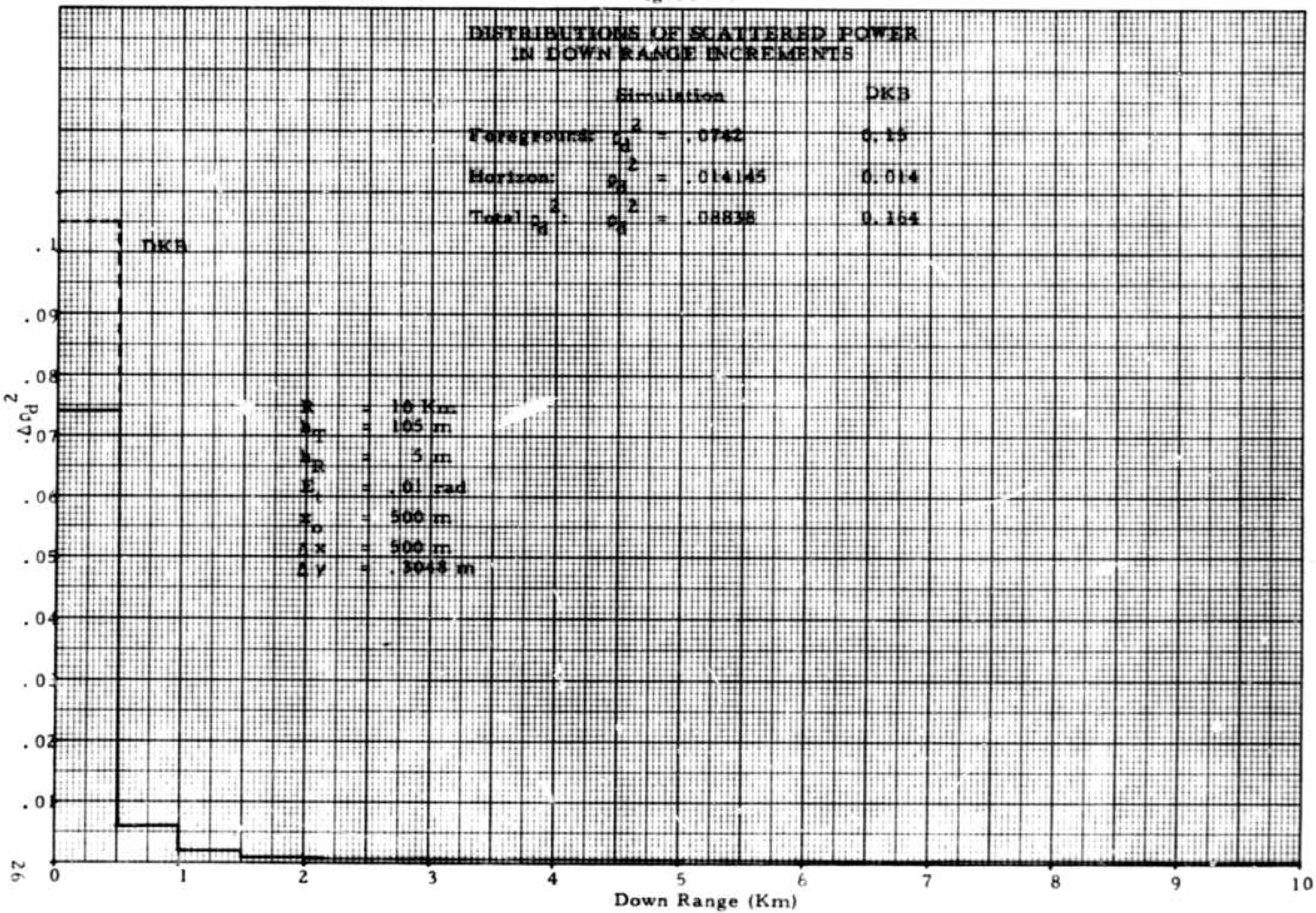
PROGRAM OUTPUT

- MEASUREMENT MODE
  - DIRECT POWER RETURN
  - REFLECTED POWER RETURN FOR EACH SCAN BEAM POSITION
  - REFLECTED POWER RETURN AS A FUNCTION OF DOWN RANGE AND CROSS RANGE DISTANCES

- TRACKING MODE
  - ELEVATION ERROR VS GROUND RANGE
  - AZIMUTH
  - RANGE

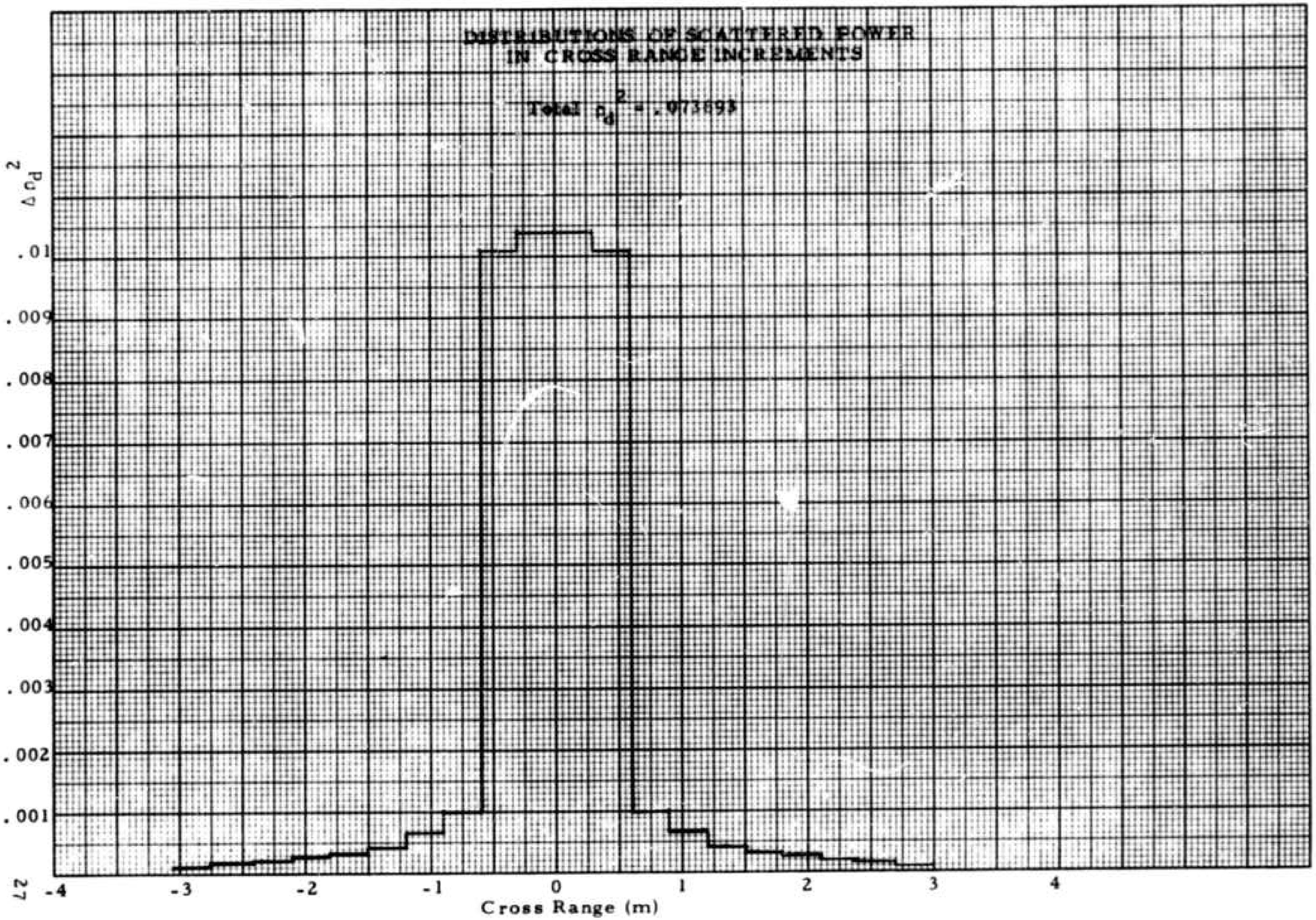
  ERRORS AS TIME PERMITS

Figure 21.



DISTRIBUTIONS OF SCATTERED POWER IN DOWN RANGE INCREMENTS
Simulation
DKB
Foreground: σ_d^2 = .0742
0.15
Horizon: σ_s^2 = .014145
0.014
Total σ_s^2: σ_s^2 = .08838
0.164
DKB
R = 10 Km
h_T = 105 m
h_R = 3 m
E_t = .01 rad
x_o = 500 m
Δx = 500 m
Δy = .3048 m
ΔP_T^2
.1
.09
.08
.07
.06
.05
.04
.03
.02
.01
0
1
2
3
4
5
6
7
8
9
10
Down Range (Km)

Figure 22.


DISTRIBUTIONS OF SCATTERED POWER
IN CROSS RANGE INCREMENTS
Total σ_d^2 = .073893
$\Delta\sigma_d^2$
.01
.009
.008
.007
.006
.005
.004
.003
.002
.001
-4
-3
-2
-1
0
1
2
3
4
Cross Range (m)

K•E 10 X 10 TO ½ INCH 7 X 10 IN. ALBANENE® KEUFFEL & ESSER CO. 46 1327 MADE IN U.S.A.

Figure 23.

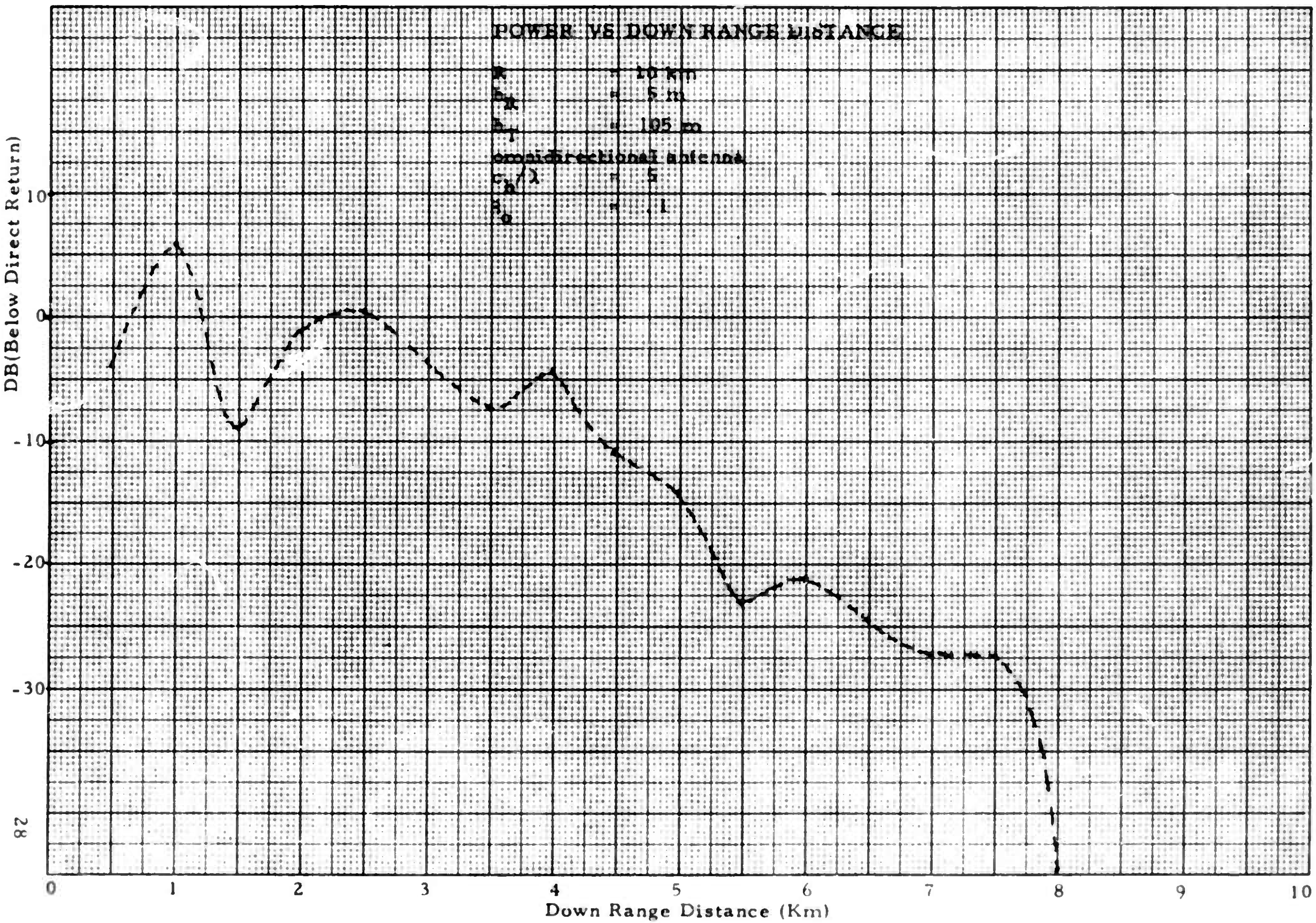


Figure 24.

DATA ANALYSIS

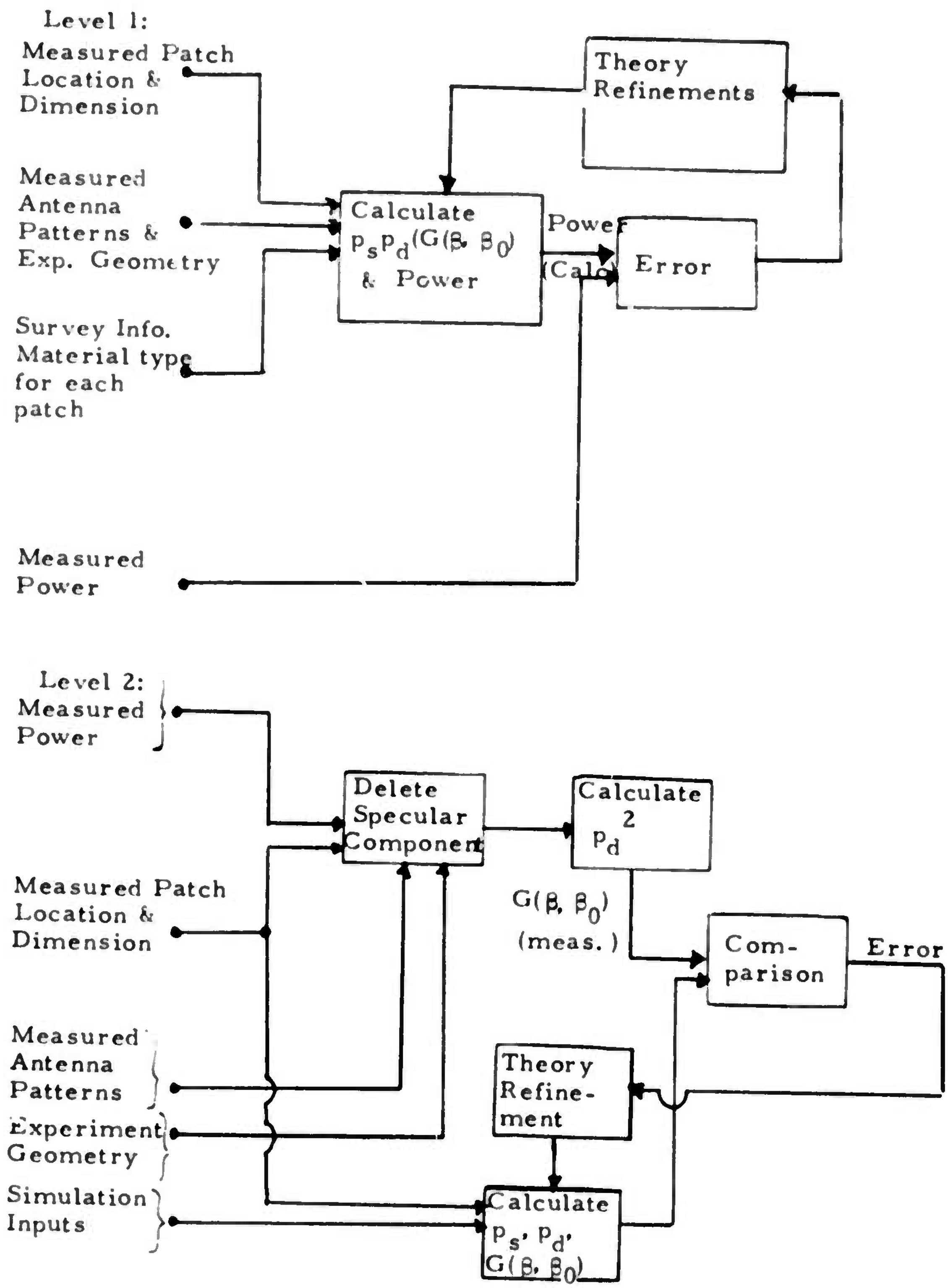


Figure 25.

SITE SELECTION

A. Uniform terrain

1. Flat cement
2. Sand
3. Grass
4. Water (calm)

B. Non-uniform terrain

1. Hills, hummocks, etc.
2. Rough sea
3. Mixed terrain features

C. Air space usage

1. Regions restricted against air traffic
2. Regions with minimal air traffic
3. Airports and Air Force bases
   (Grenier, Westover, Otis)

Figure 26.

SUPPORT FOR TRANSMITTER

A. Towers, tall buildings

Advantages:

1. Transmitter position firmly fixed
2. No wind or weather limitations
3. Operation night or day
4. Low cost

Disadvantages:

1. Terrain restricted to specific locations
2. Severe altitude restriction
3. Possible unplanned multipath

B. Helicopter

Advantages:

1. Can be taken anywhere
2. Any reasonable altitude readily obtained
3. Tether not required

Disadvantages:

1. Probably not practical to hover in one spot
2. May be difficult to determine altitude
3. Requires patient cooperative pilot
4. Requires reliable ground-to-air communications
5. Severe wind and weather limitations
6. Operation only in daylight
7. High cost

C. Tethered balloon

Advantages:

1. Can be taken anywhere
2. Position in space can be fairly firmly fixed
3. Altitudes as high as we will want are attainable
4. Can probably be used in fairly severe weather
5. Can probably be used at night, if required
6. Moderate cost

Disadvantages:

1. Tether(s) required
2. May be difficult to handle under some conditions
3. FAA requirements for banners on the tether lines in daylight and lights at night, except in restricted locations
4. Provisions, equipment, and manpower required for storing, inflating, launching, and maneuvering

Figure 27.

A FEW CONSIDERATIONS RELATING TO THE TETHERED BALLOON

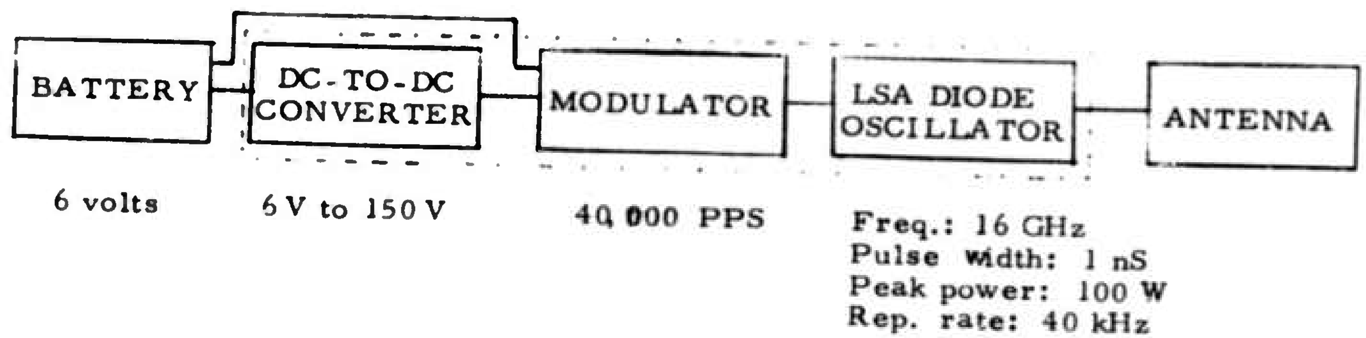
A. Shape

1. Spherical
2. Aerodynamic, e.g., elongated, with fins (Kytoon)
3. Vee-balloon (Goodyear)

B. Accessory equipment

1. Tether line(s)
2. Banners, lights
3. Winch
4. Tie-down hardware for supplemental tethers
5. Helium tanks; inflating equipment
6. Instruments to determine balloon position
   a. three theodolites
   b. transit
   c. laser radar
   d. tether angle sensor

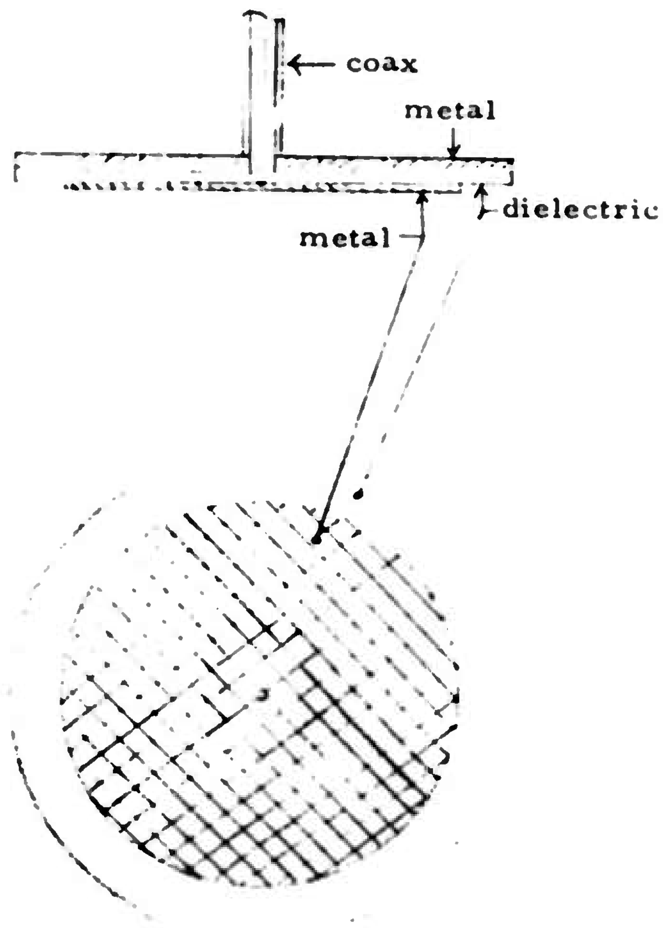
Figure 28.



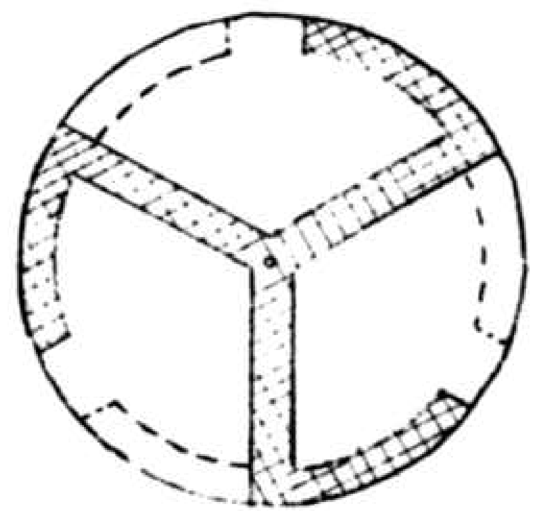
Total power consumption: 100 milliwatts

Weight (excluding battery and antenna): 12 ounces

AIRBORNE (TRANSMITTER) ELECTRONICS



FLAT DISK ANTENNA
(Vertical polarization)



TRIPLE DIPOLE ANTENNA
(Horizontal polarization)

Figure 29.

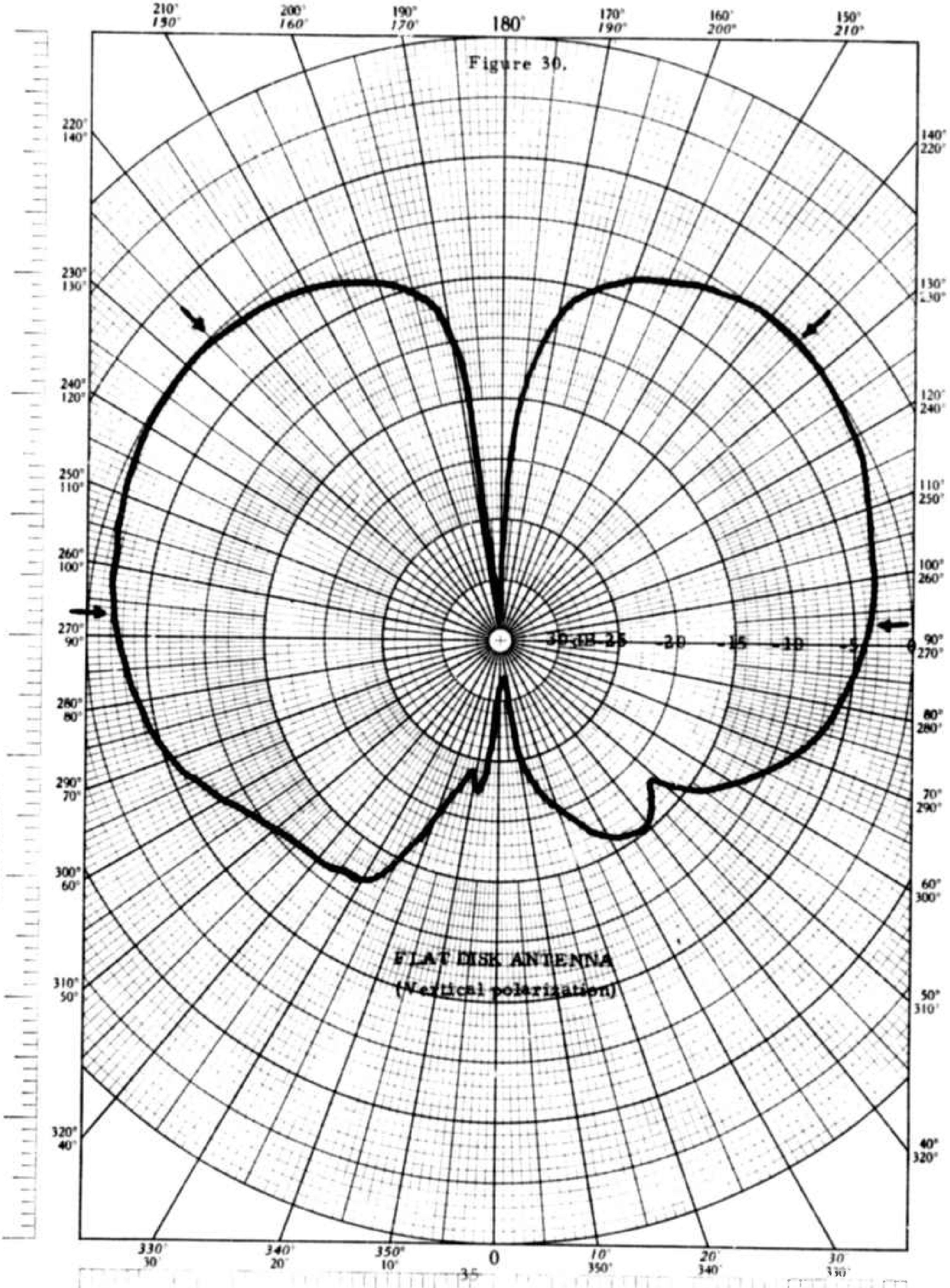
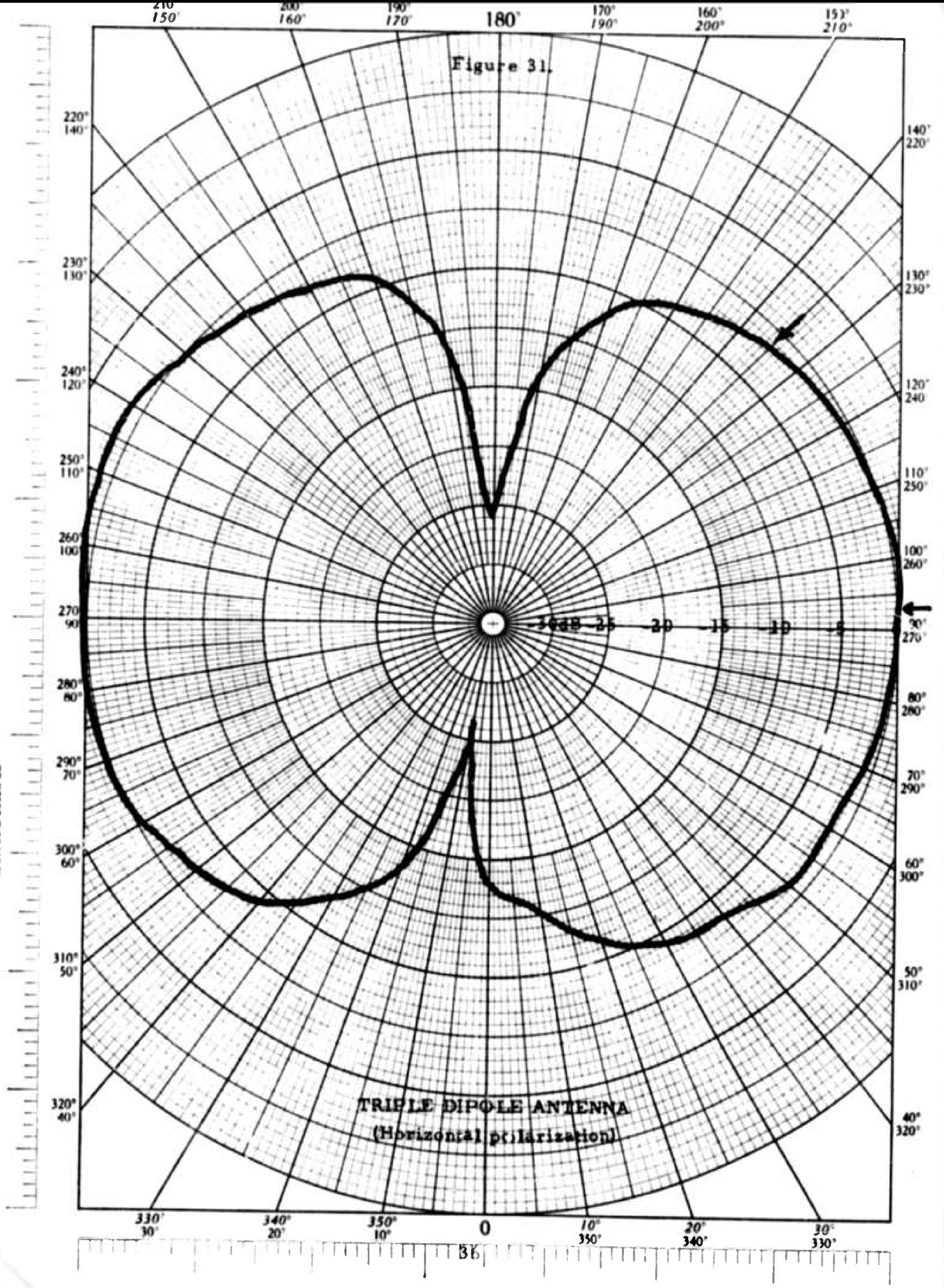
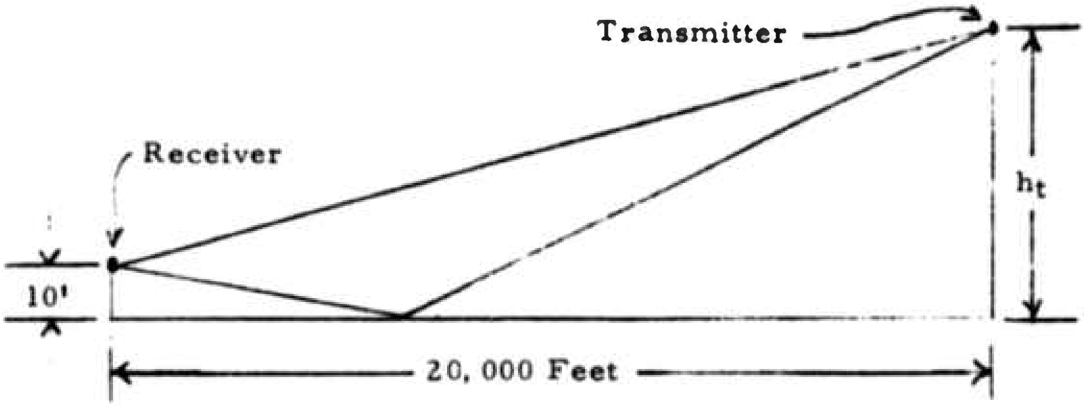


Figure 30.
FLAT DISK ANTENNA
(Vertical polarization)
180°
0
30 dB -25 -20 -15 -10 -5 0
K+E POLAR CO-ORDINATE 46 4413
KEUFFEL & ESSER CO.

Figure 31.

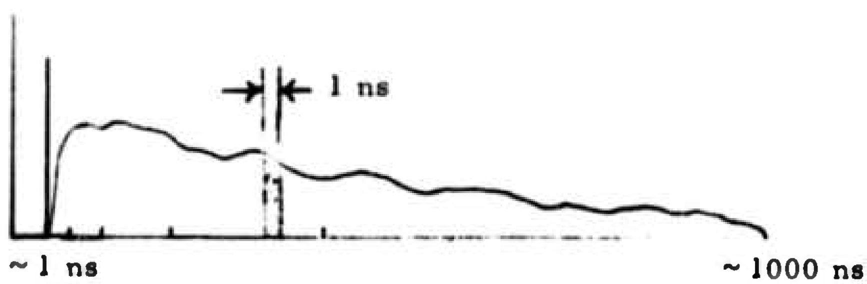


180°
-30dB
-25
-20
-15
-10
-5
0
K+E POLAR CO-ORDINATE 46 4413
KEUFFEL & ESSER CO.
TRIPLE DIPOLE ANTENNA
(Horizontal polarization)



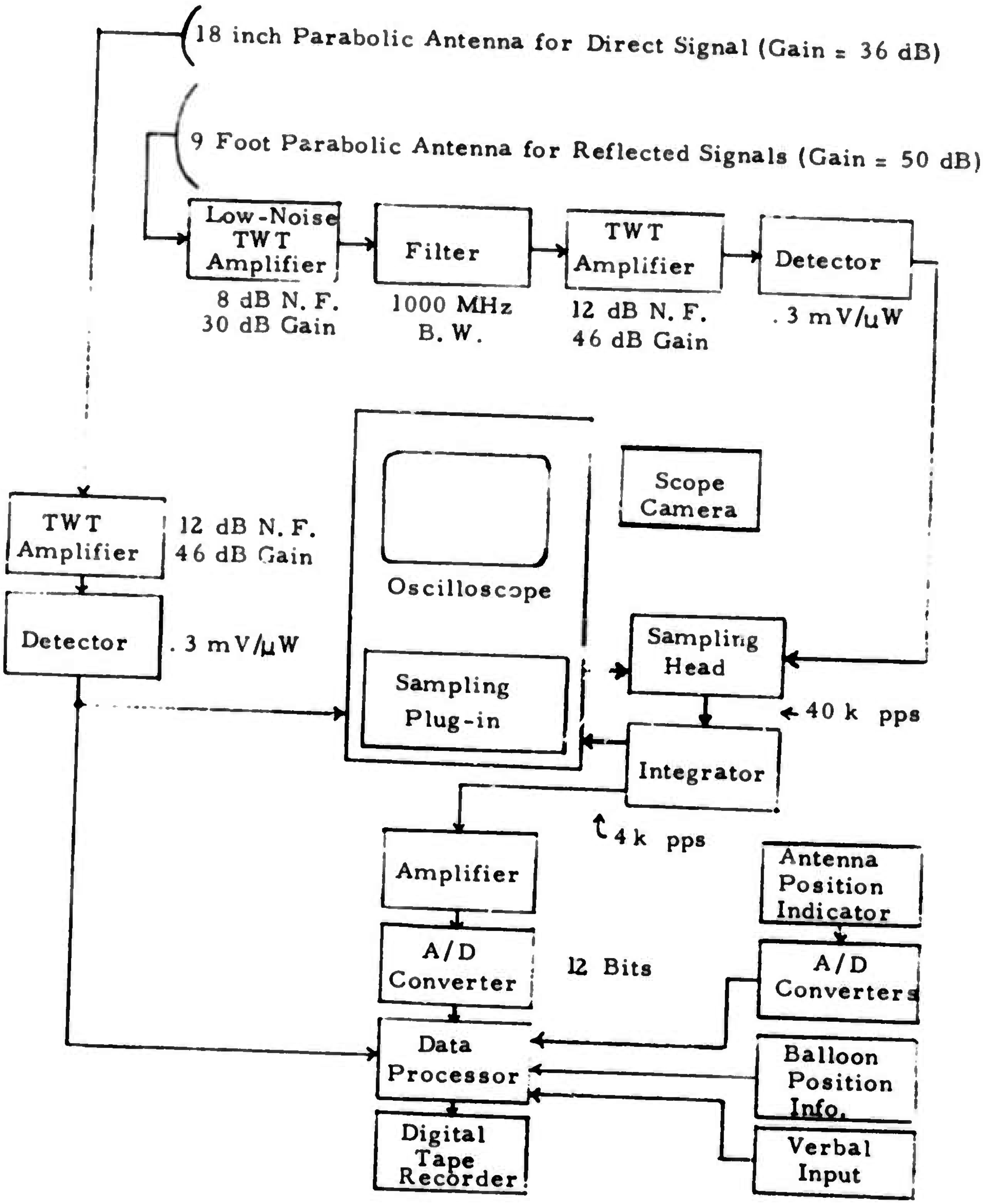
Balloon Height (h_t)	1000'	2000'
Direct Path	20024.4875	20098.7587
Shortest (Specular) Reflected Path	20025.4863	20100.7487
Longest Reflected Path	21000.0025	22000.0025

1 nanosecond → 1 foot(for one-way path)



RECEIVER PATH GEOMETRY

Figure 32.



GROUND RECEIVING EQUIPMENT

Figure 33.

Figure 34.

DIRECT PATH SIGNAL RECEPTION

18" parabolic antenna: gain = 36 dB	Bandwidth = 1 GHz
Signal level = -46 dbm	KTB = -84 dbm
	Noise figure = 12 dB
	Noise level = -72 dbm

Hence, the signal is 26 dB above noise.

TWT gain = 46 dB; therefore, the signal at the detector = 0 dbm.
Detector sensitivity = 0.3 mV/uW $\therefore$ trigger signal = 0.3 volt.

REFLECTED PATH SIGNAL RECEPTION

9' parabolic antenna: gain = 50 dB	Bandwidth = 1GHz
Assume 30 dB reflection loss	KTB = -84 dbm
Signal level = -62 dbm	Noise figure = 8 dB
	Noise level = -76 dbm

Hence, the signal is 14 dB above noise. Video integration may be used to improve the S/N ratio.

First TWT gain = 30 dB; assume 4 dB filter loss; second TWT gain = 46 dB. The net gain is 72 dB; therefore, the signal at the detector is +10 dbm. The noise level at the detector is -4 dbm. Both levels may be reduced with no S/N penalty by reducing the gain of the second TWT.